Polarized Photocathode Research Collaboration PPRC

R. Prepost – University of Wisconsin

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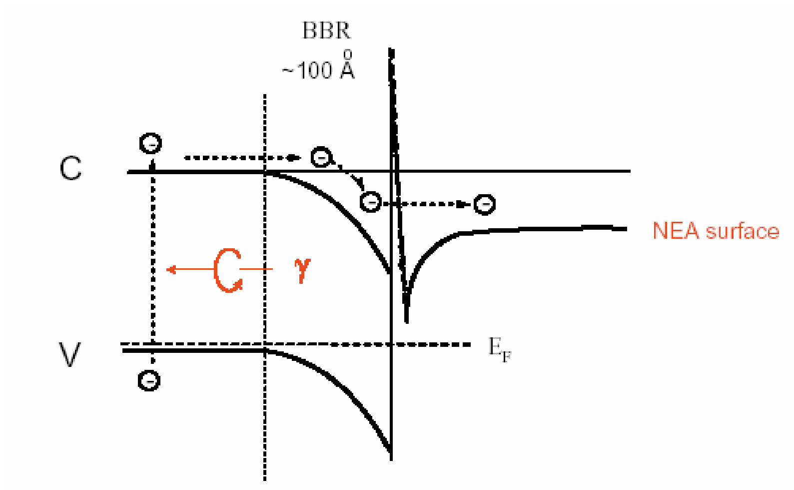
Some Considerations

- Technique is Bandgap Engineering of Strained GaAs.
- Polarization will be < 100% - But 90% possible.
- Active layer must be < 10% of photon absorption length to preserve strain and polarization.
- Uniform Strain over larger thickness in principle possible with Superlattice structures
- Strained GaAs used at SLAC since 1986 with ~85% Polarization and ~.2% QE.
- R & D has been continuous since 1985.

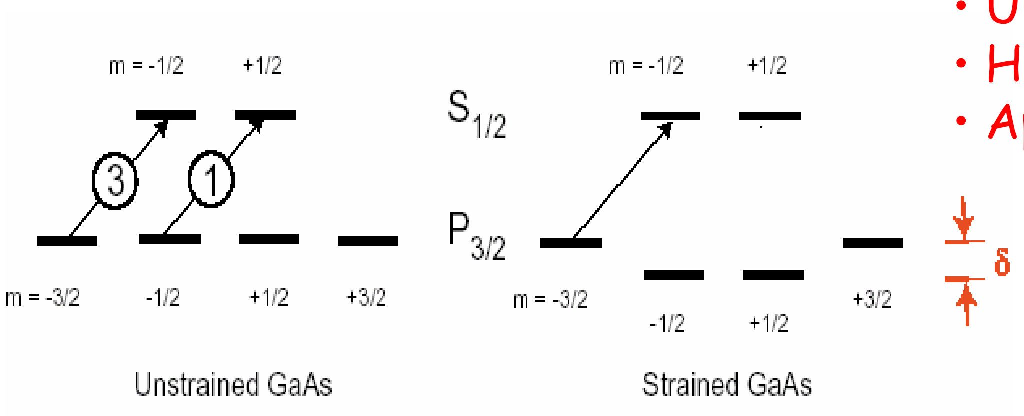
Outline

- Polarized photoemission
- Standard SLC photocathode
- Surface charge limit
- Charge limit vs. doping
- Polarization vs. doping
- High gradient doped strained GaAsP
- High gradient doped strained superlattice
- Atomic-hydrogen cleaning
- Summary

Polarized photoemission



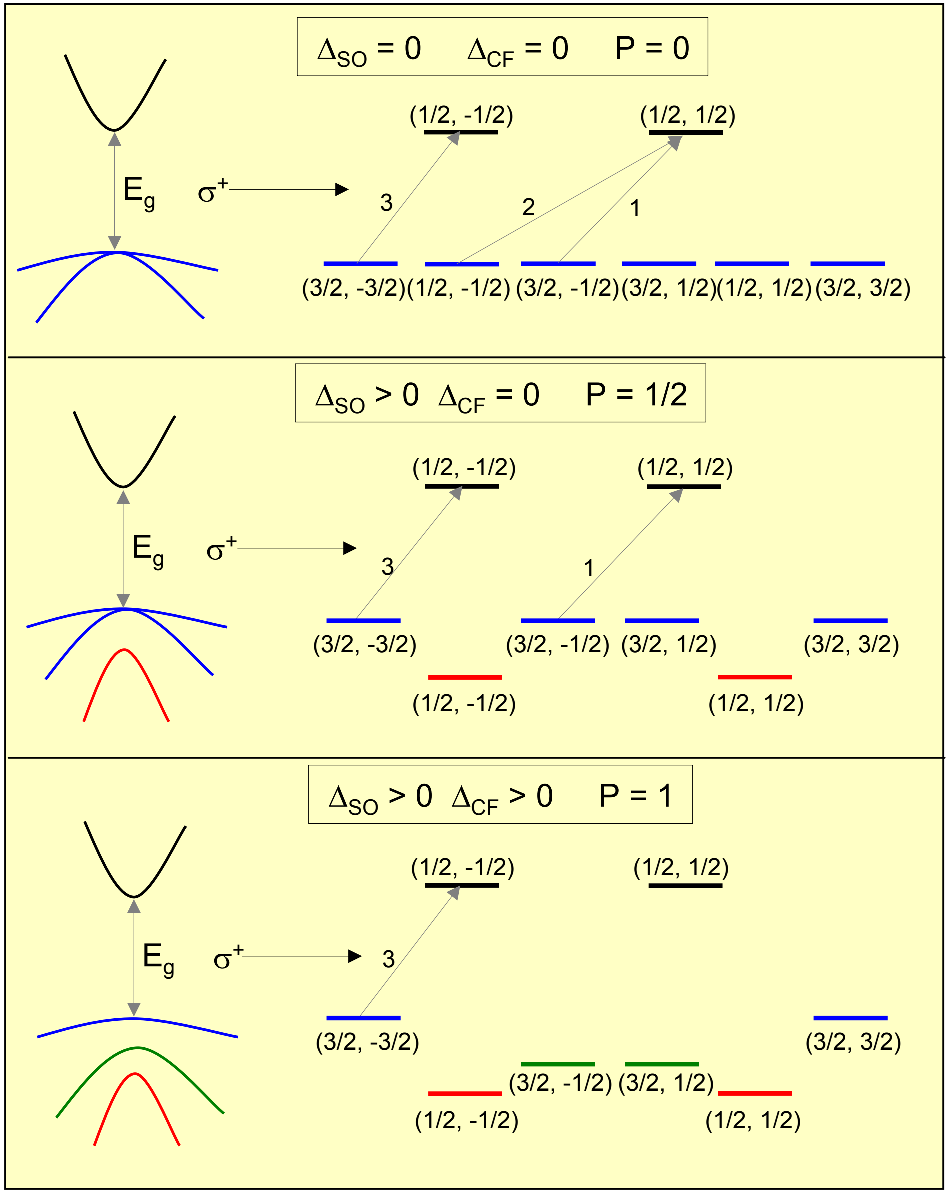
- Circularly polarized light excites electron from valence band to conduction band
- Electrons drift to surface
  L < 100 nm to avoid depolarization
- Electron emission to vacuum from Negative-Electron-Affinity (NEA) surface



NEA Surface –
Cathode "Activation"

- Ultra-High-Vacuum < 10^{-11} Torr
- Heat treatment at 600° C
- Application of Cesium and NF_3

Schematic diagram of near-gap optical transition for circularly polarized light



$$P = \frac{\left| I\downarrow - I\uparrow \right|}{\left| I\downarrow + I\uparrow \right|}$$

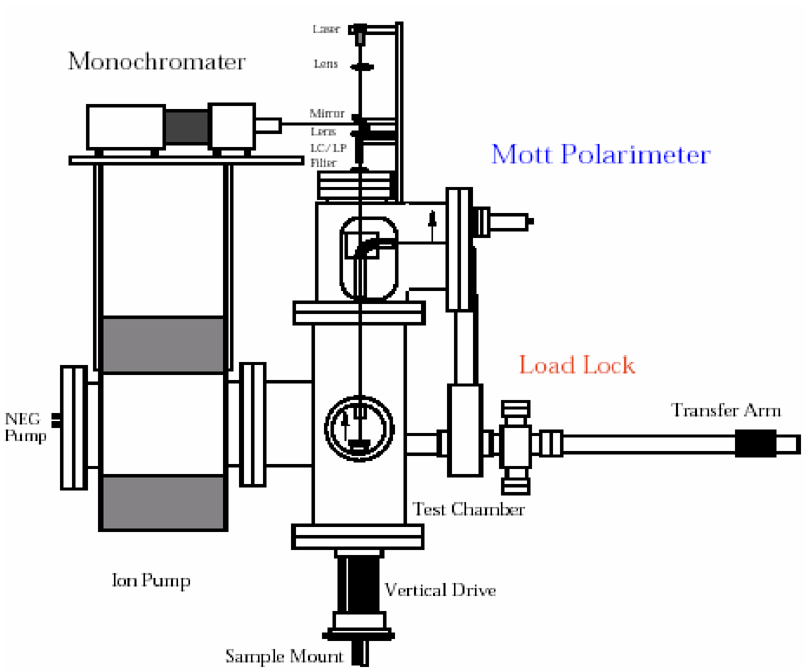
$$I = \left| \left\langle \Psi_f \middle| H_{\text{int}} \middle| \Psi_i \right\rangle \right|^2$$

$$H_{\text{int}} = X + iY$$ for σ^+ light

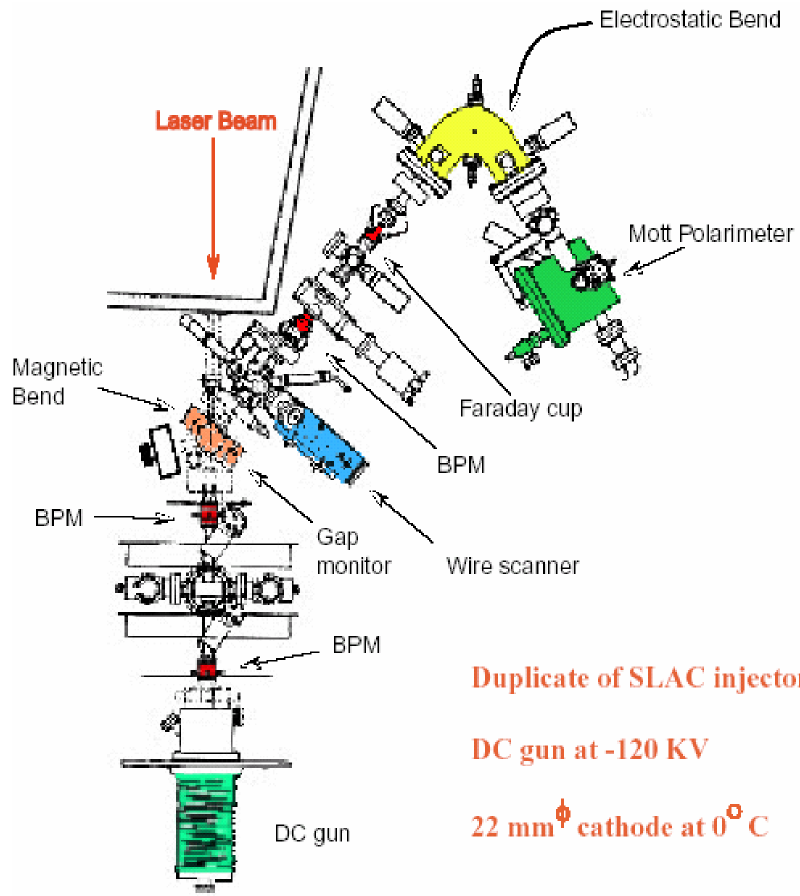
Ideal material for SPES application

- Direct band gap
- Large spin-orbit splitting
- Large and positive crystal field splitting

Facilities



- QE and Polarization at 20 kV



Duplicate of SLAC injector

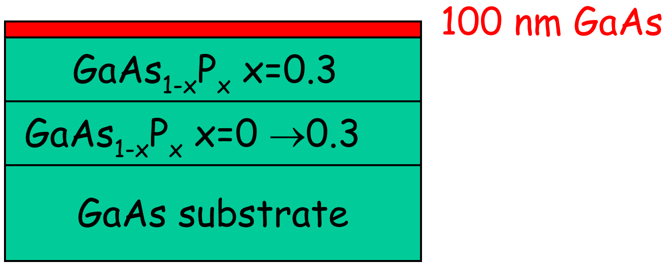
DC gun at -120 KV

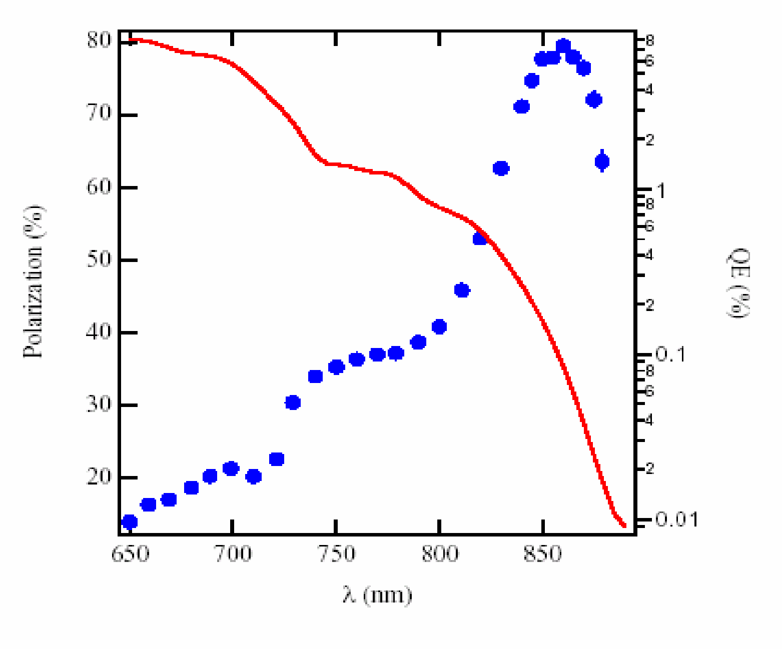
22 mm$^{\phi}$ cathode at 0^{o} C

- QE and Polarization at 120 kV under accelerator condition

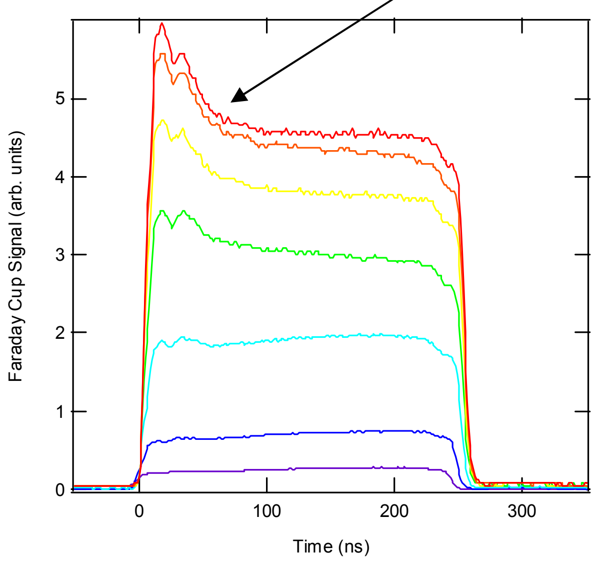
Standard SLC Strained GaAs

- 100 nm GaAs grown on GaAsP
- Uniformly doped at 5×10^{18} cm^{-3}
- Peak polarization ~80%
- QE ~0.2 - 0.3%
- Max. charge ~7 $\times10^{11}$ e-/270ns

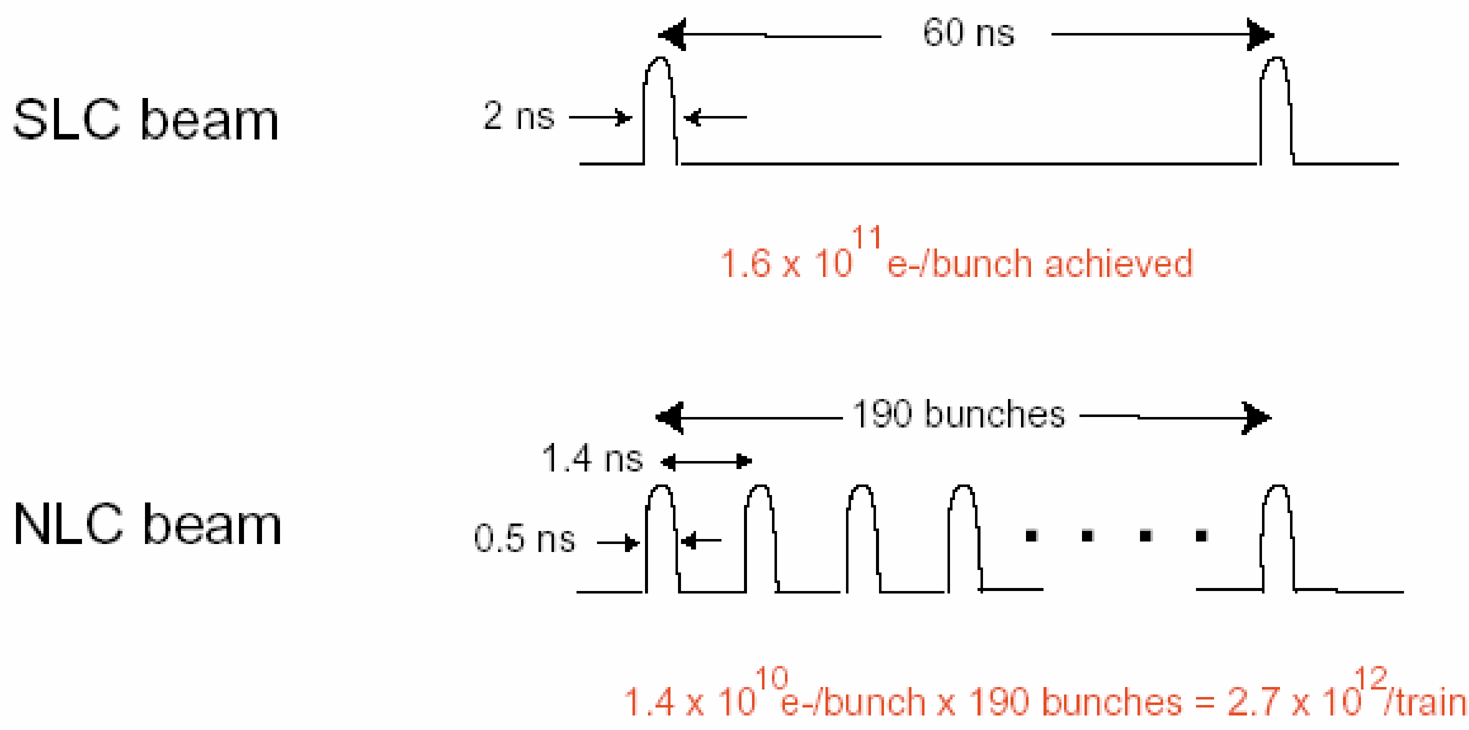




Charge saturation

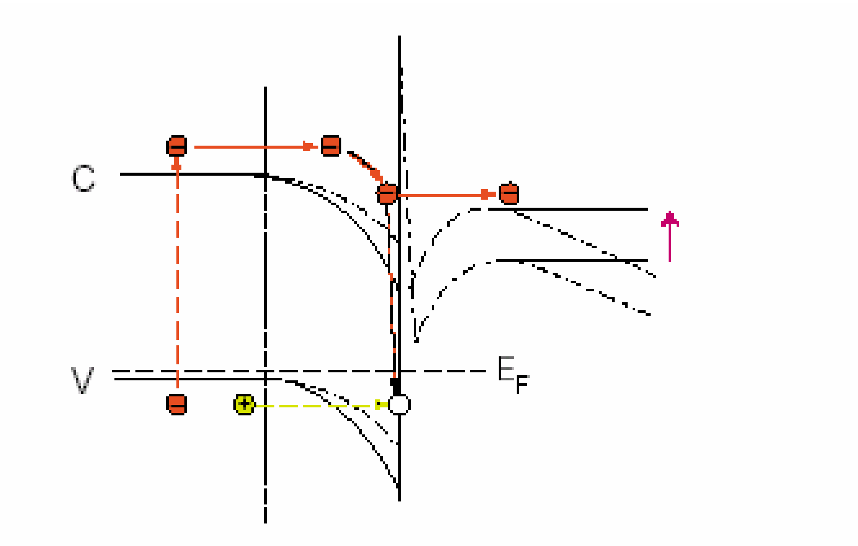


Beam structure



Surface Charge Limit

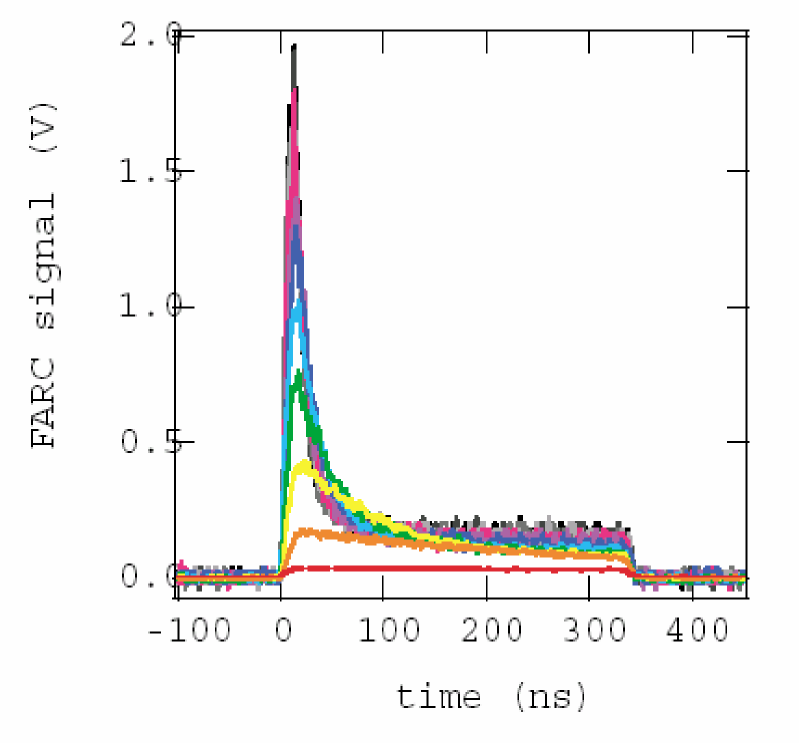
- Photon absorption excites electrons to conduction band
- Electrons can be trapped near the surface; electron escape prob. < 20%
- Electrostatic potential from trapped electrons raises affinity
- Affinity recovers after electron recombination
- Increasing photon flux counterproductive at extremes



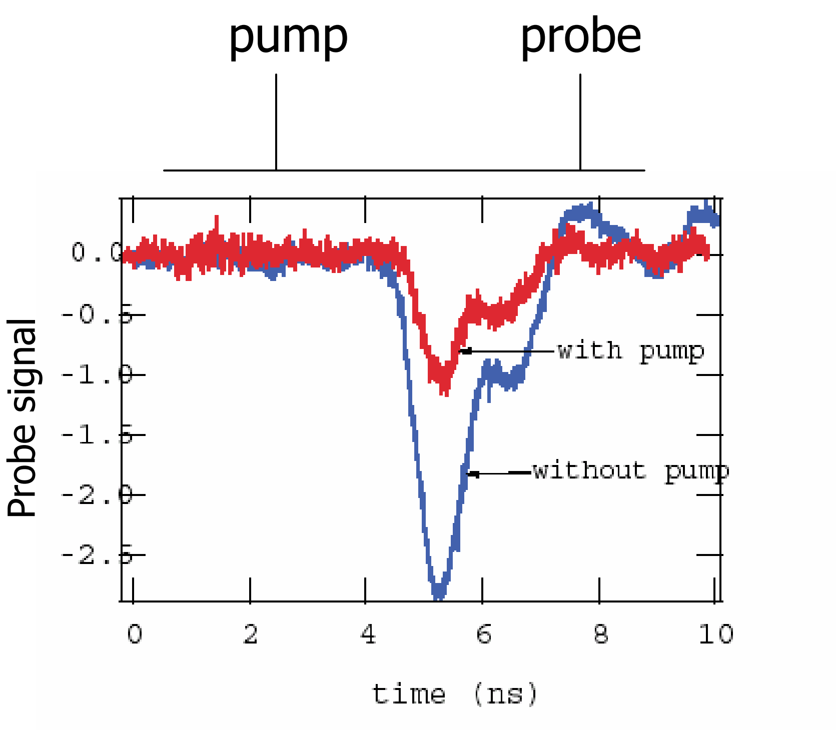
TESLA does not have a charge limit problem.

Charge limit (cont.)

Long pulse

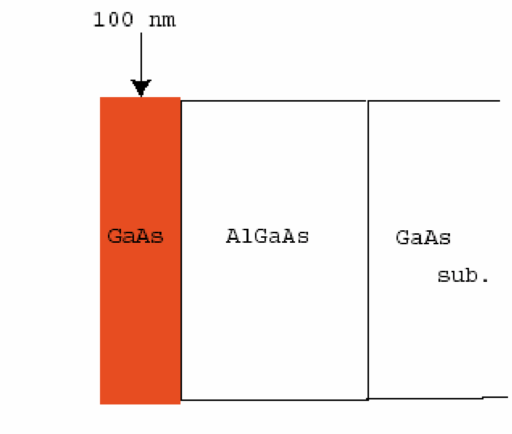


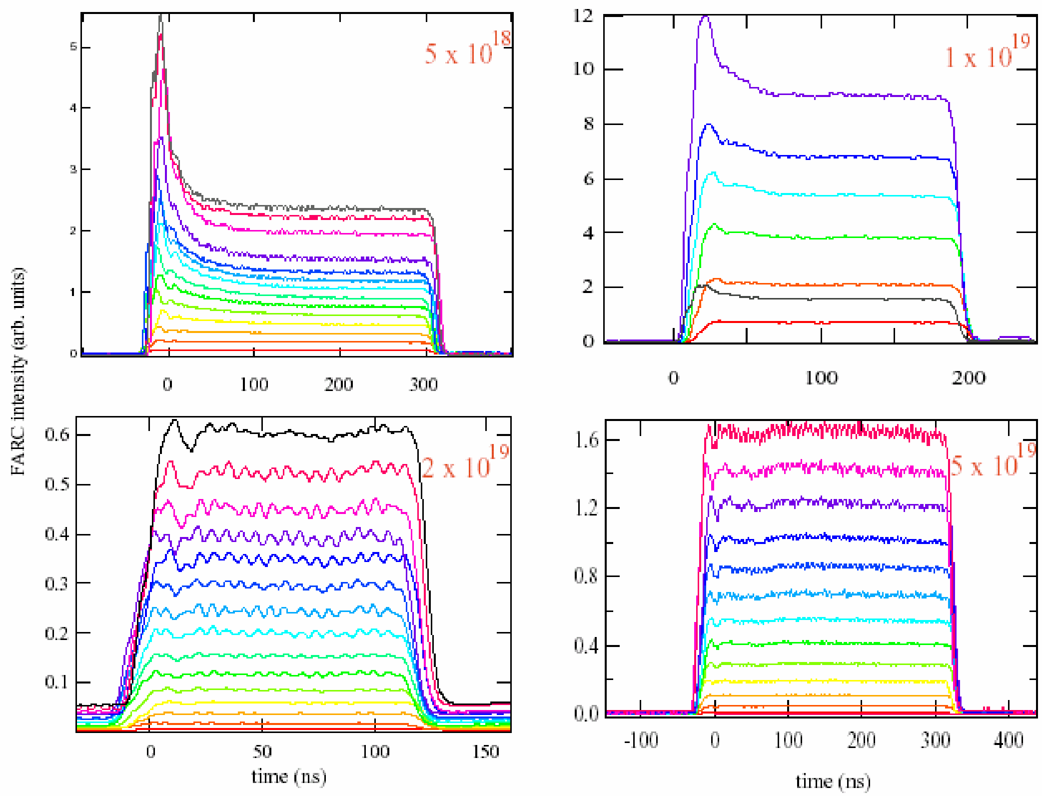
Two short pulses



Higher doping solves charge limit problem.

Phys. Lett. A282, 309 (2001)

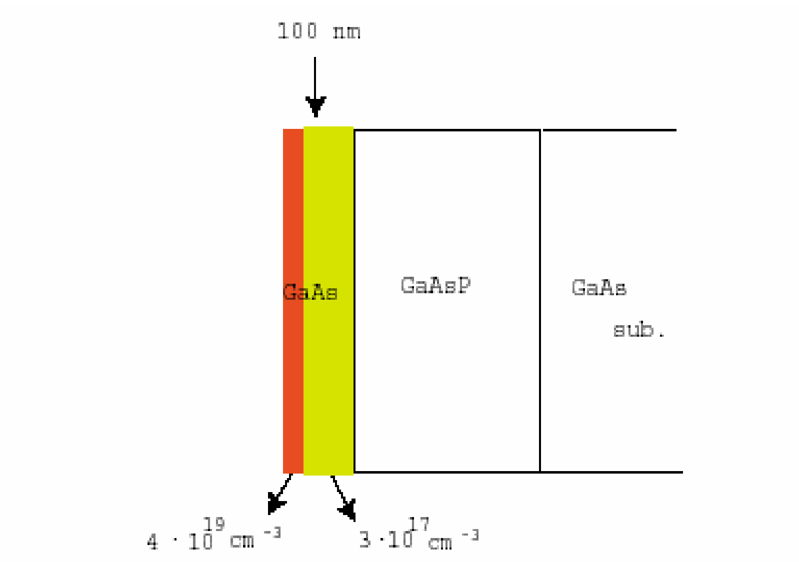


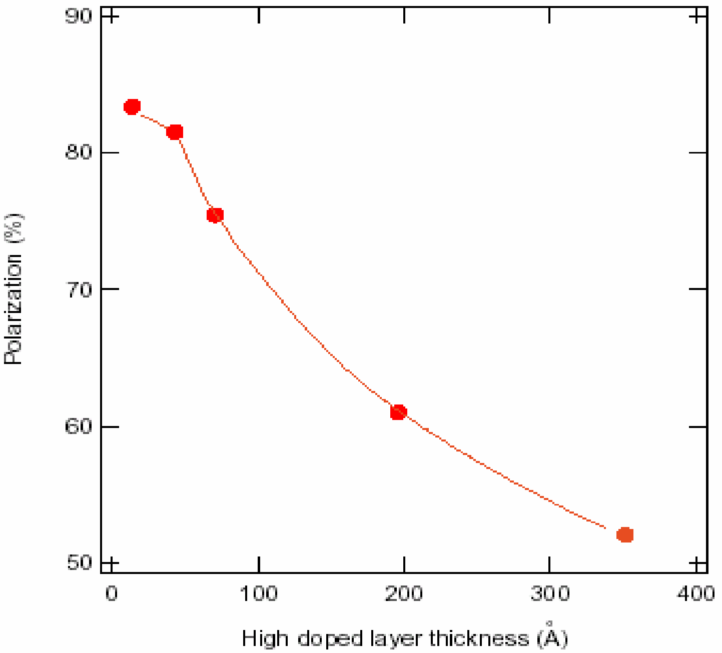


Four samples with different doping level:

- 5×10^{18} cm^{-3}
- 1×10^{19} cm^{-3}
- 2×10^{19} cm^{-3}
- 5×10^{19} cm^{-3}

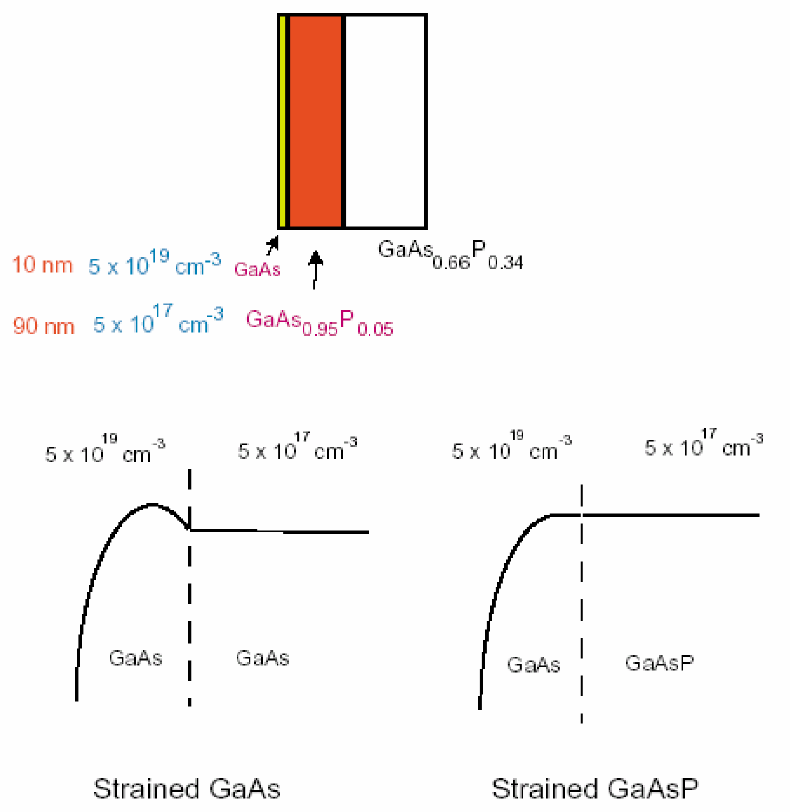
But higher doping depolarizes spin.

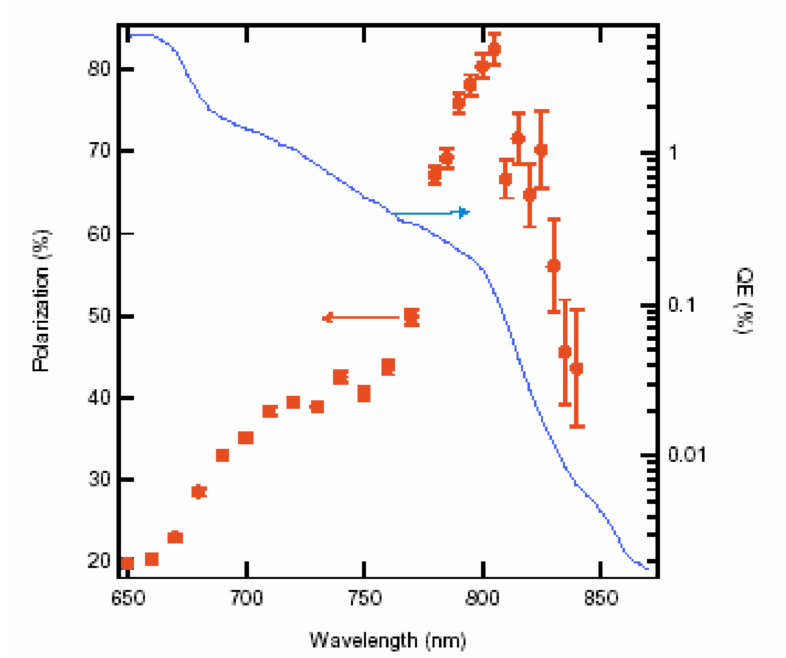




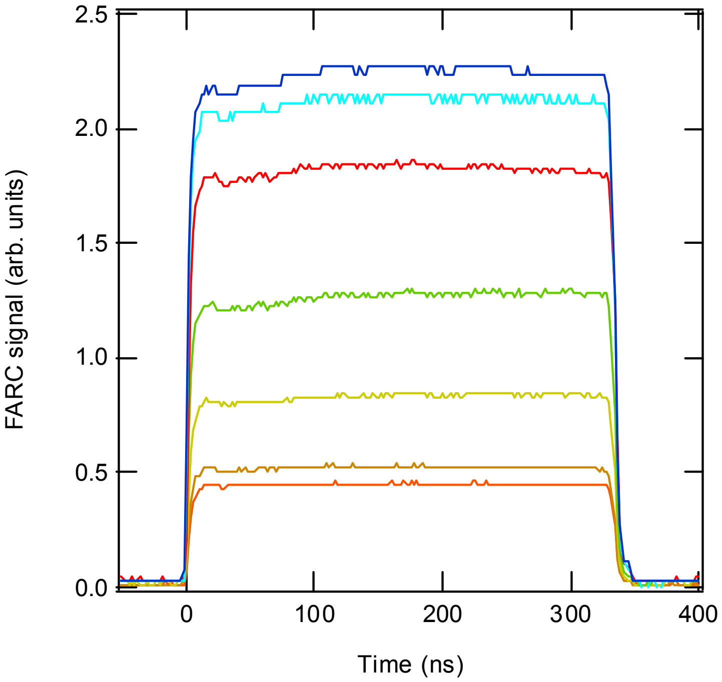
High-gradient doped strained GaAsP

NIM A492, 199 (2002)

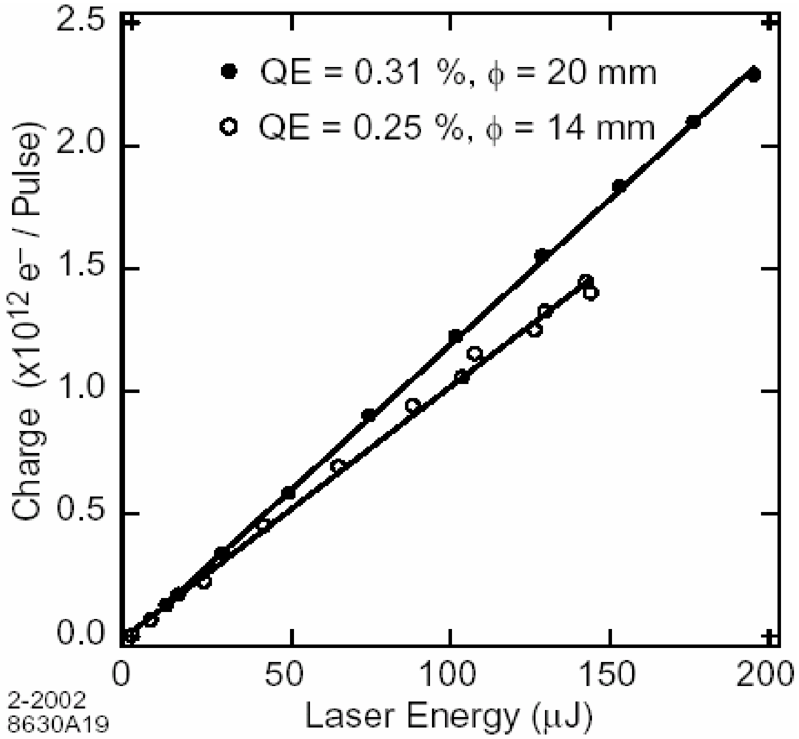




80% Polarization and No charge limit



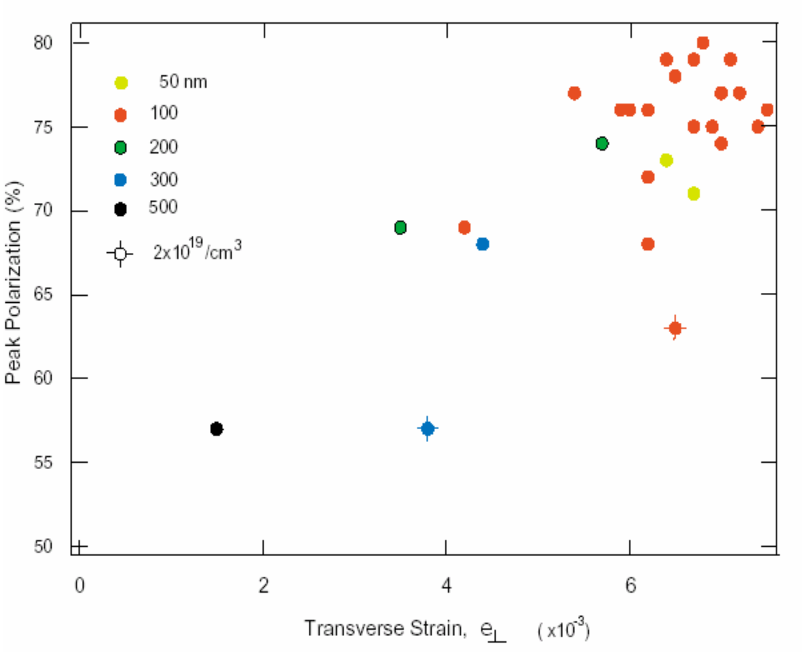
E158 cathode

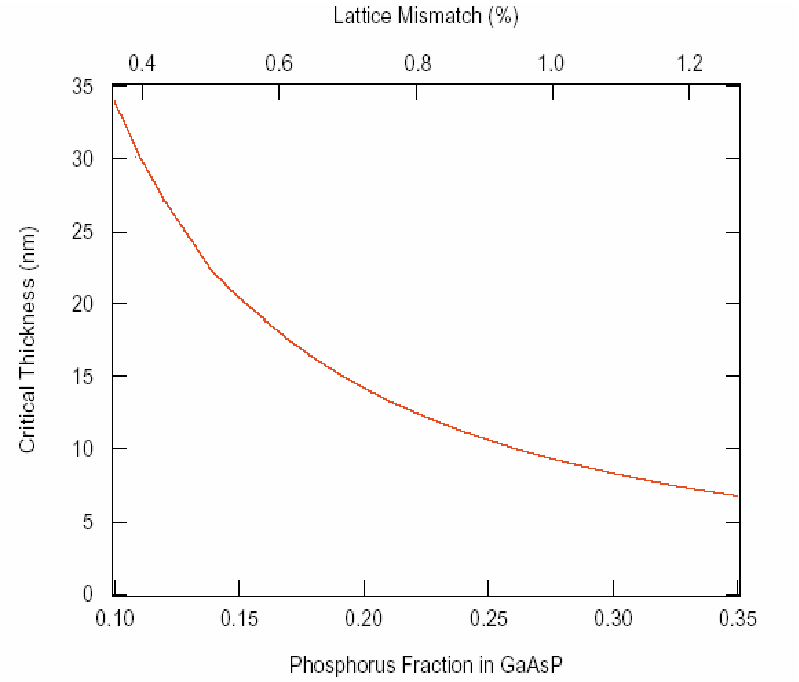


But polarization is still 80%.

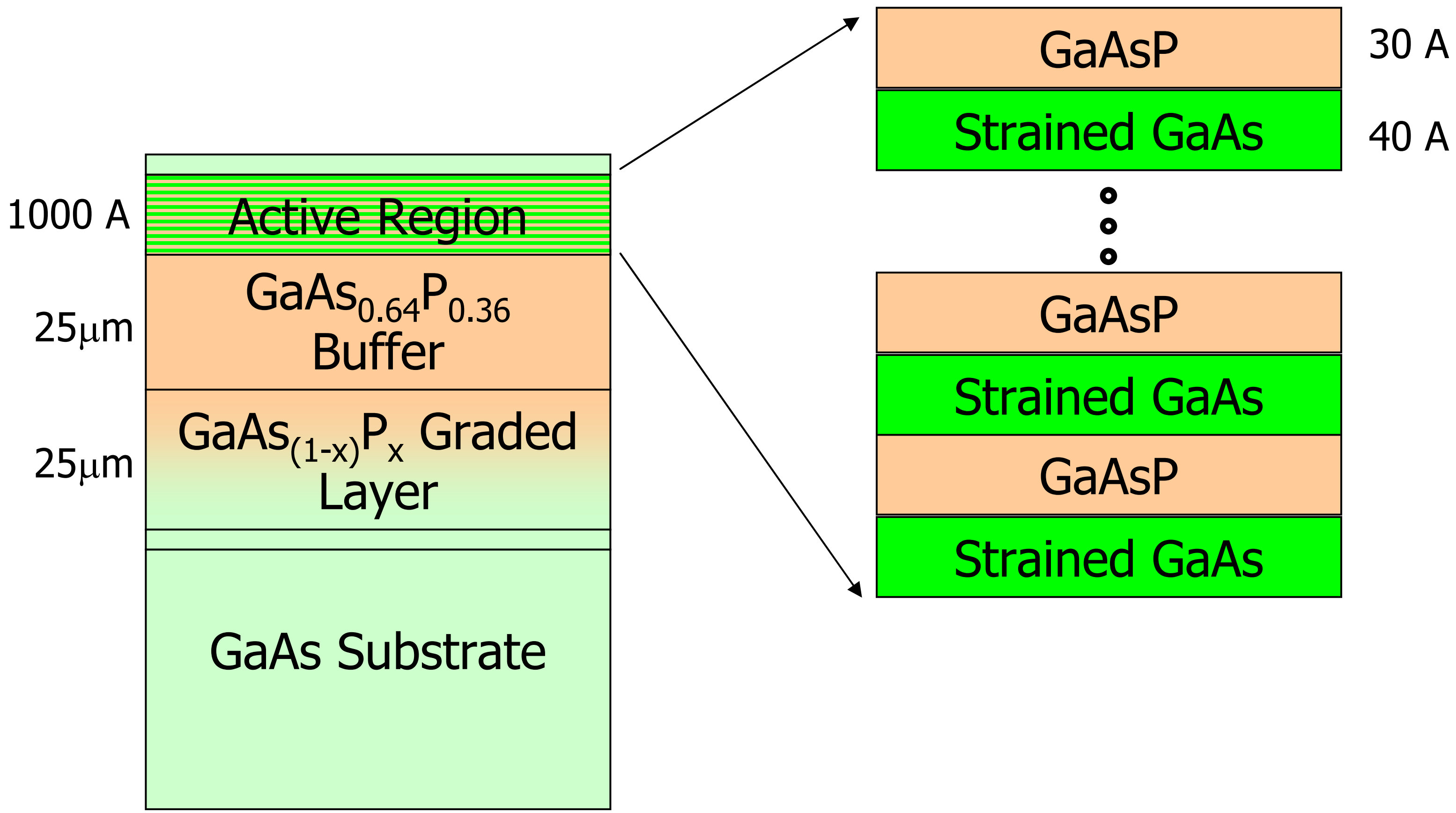
Strain relaxation

Actual strain is 80% of design





Strained-superlattice



SBIR with SVT Associates

"Advanced Strained-Superlattice Photocathodes for Polarized Electron Souces"

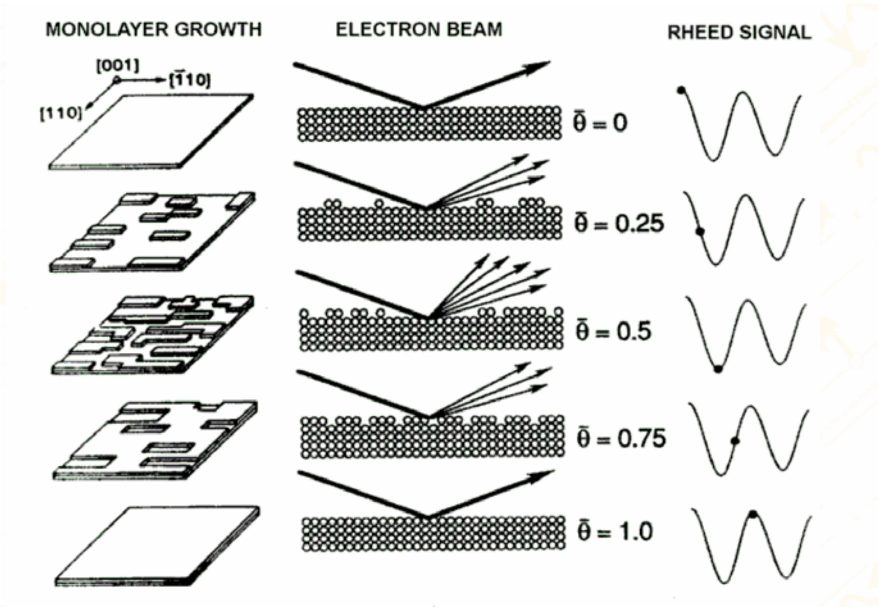
- July 2001 SBIR Phase I awarded
  Very first sample produced 85% polarization
- Sep. 2002 SBIR Phase II awarded

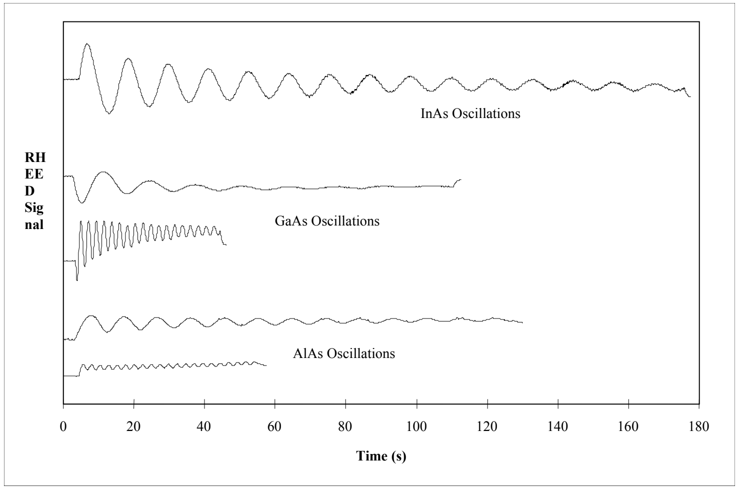
	SLC photocathode
• MBE growth	MOCVD growth
• Be doped	Zn doped

MBE- In Situ Growth Rate Feedback

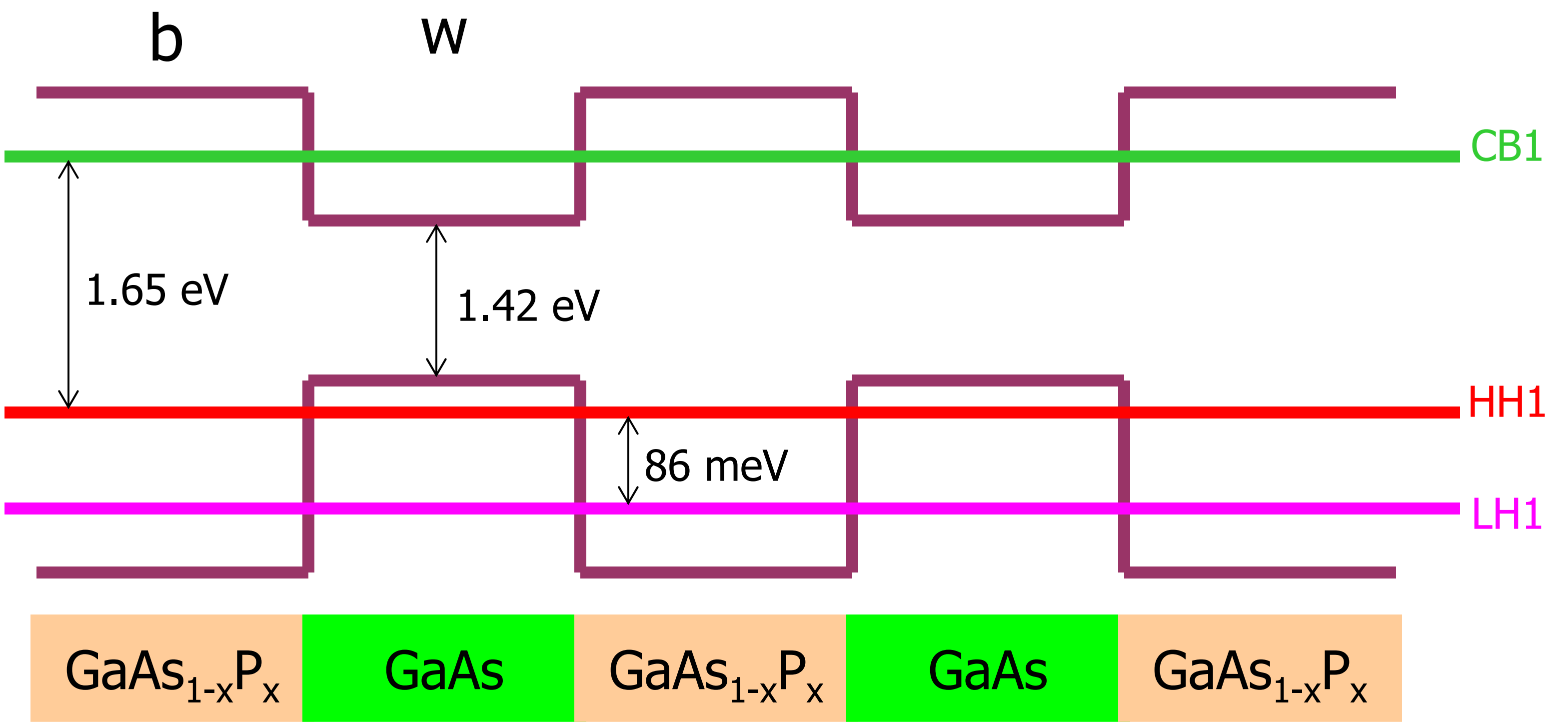
Monitoring RHEED image intensity versus time provides layer-by-layer growth rate feedback

Growth at monolayer precision





Strained-superlattice band structure



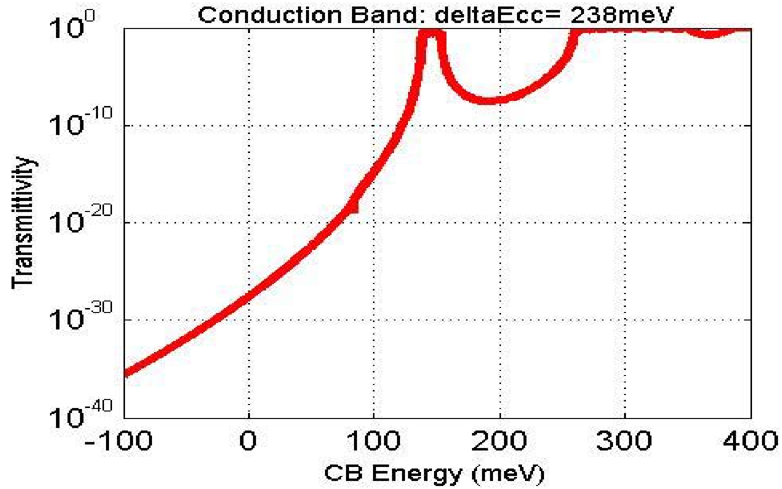
Parameters:
barrier layer thickness, 30 Å < b < 100 Å
well layer thickness , 30 Å < w < 100 Å
phosphorus fraction , 0.3 < x < 0.4
No. of periods , active layer ~ 1000 Å

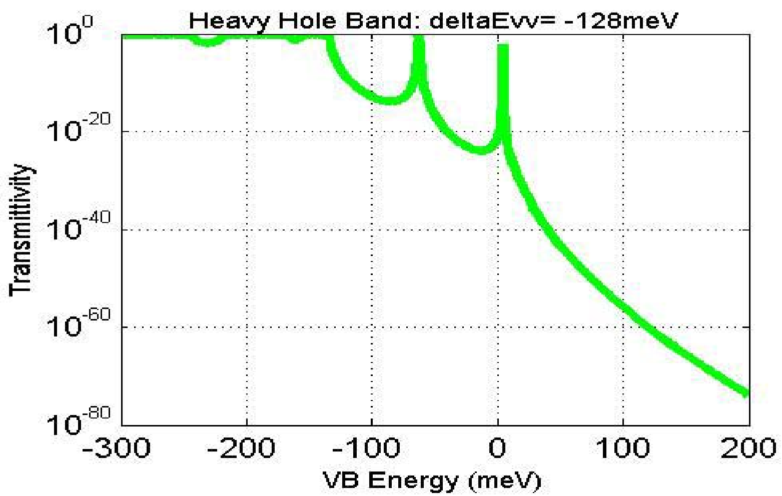
Multiple Quantum Well Simulation

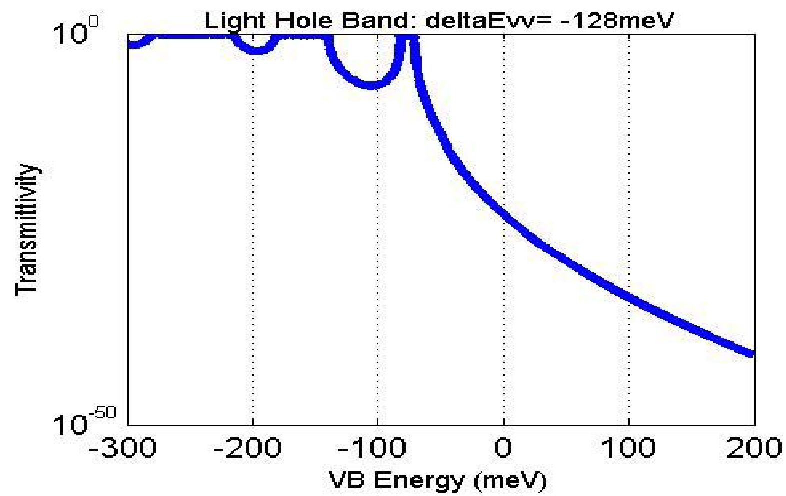
Number of Wells = 10
x in GaAs(1-x)P(x) Barrier = 0.30
Well Width = 50 A
Barrier Width = 50 A

Width is measured wrt 1/10000 the peak

Miniband width in CB1 = 25 meV
Miniband width in HH1 = 0 meV
Miniband width in LH1 = 18 meV

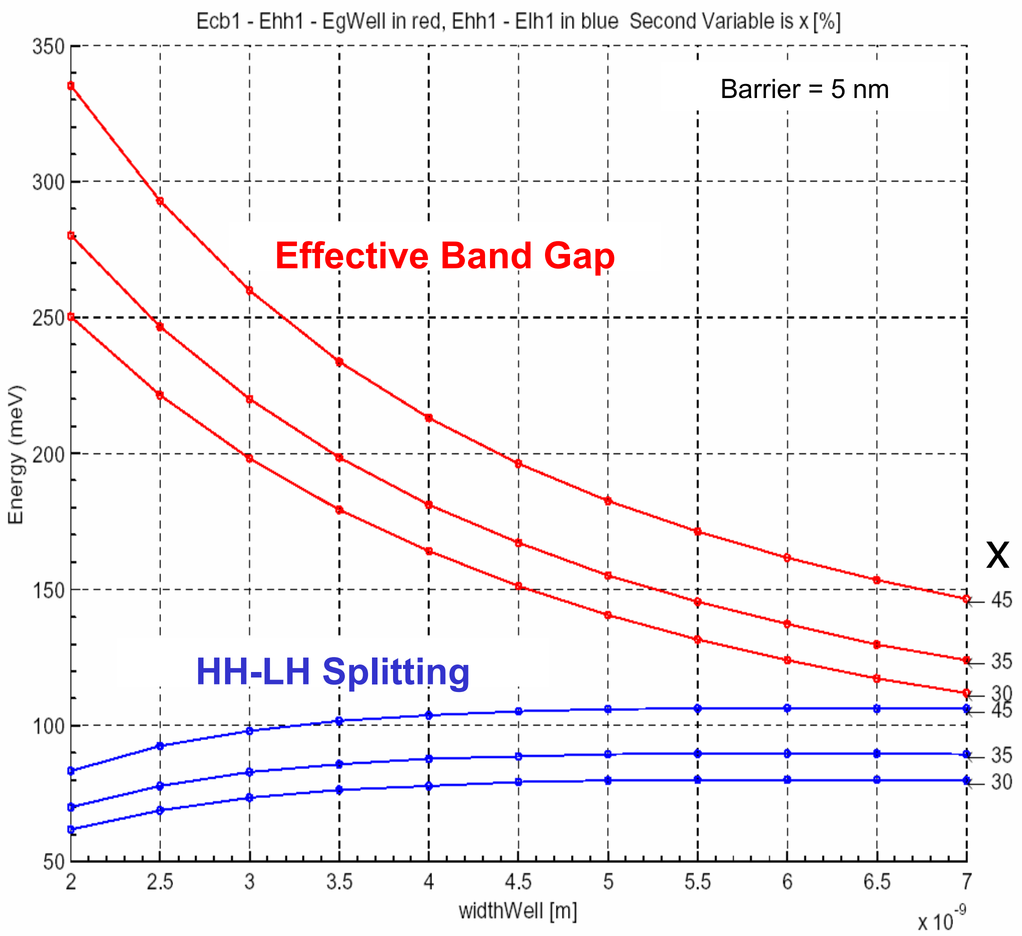






Multiple Quantum Well Simulation

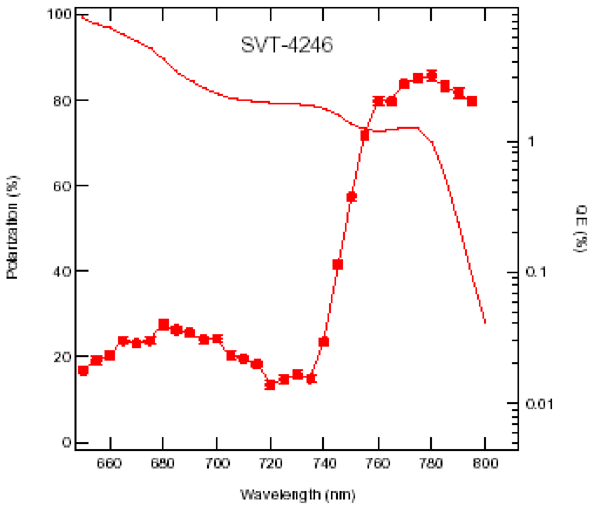
- QE ~ Band Gap
- Polarization ~ HH-LH Splitting

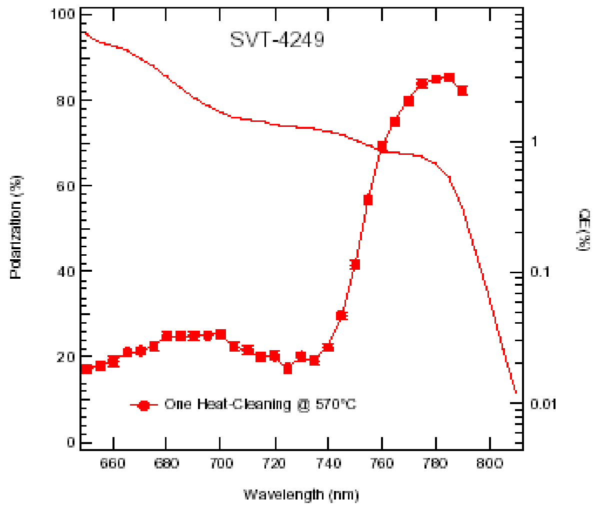


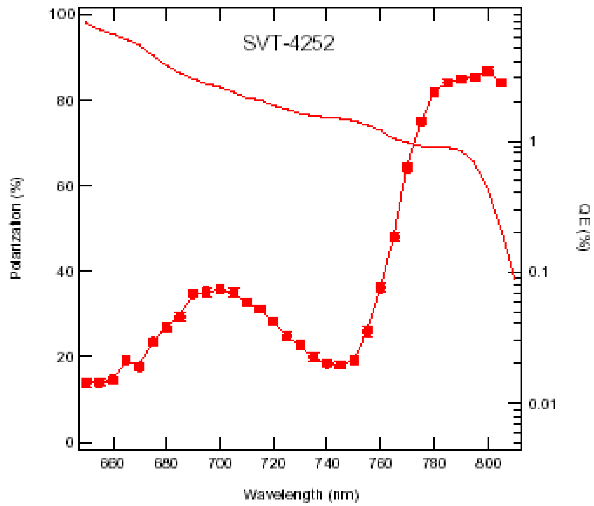
High gradient-doped superlattice GaAs/GaAsP

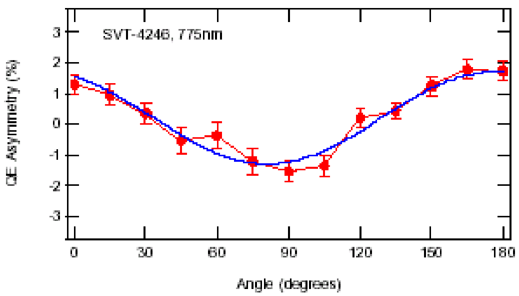
Cathode Test Lab

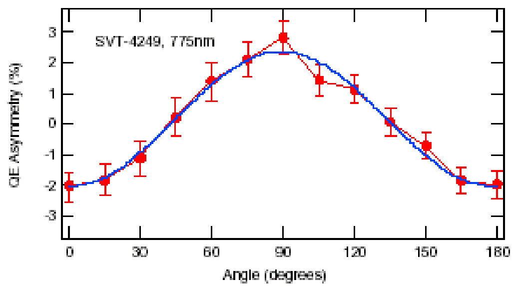
- Measurements on SVT-4246, SVT-4249 and SVT-4252.

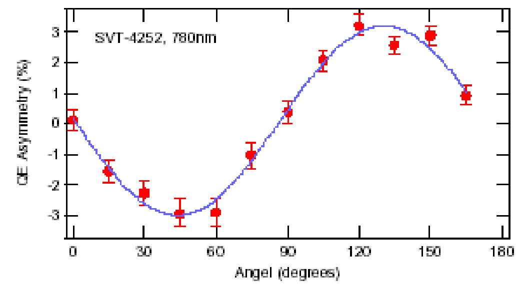










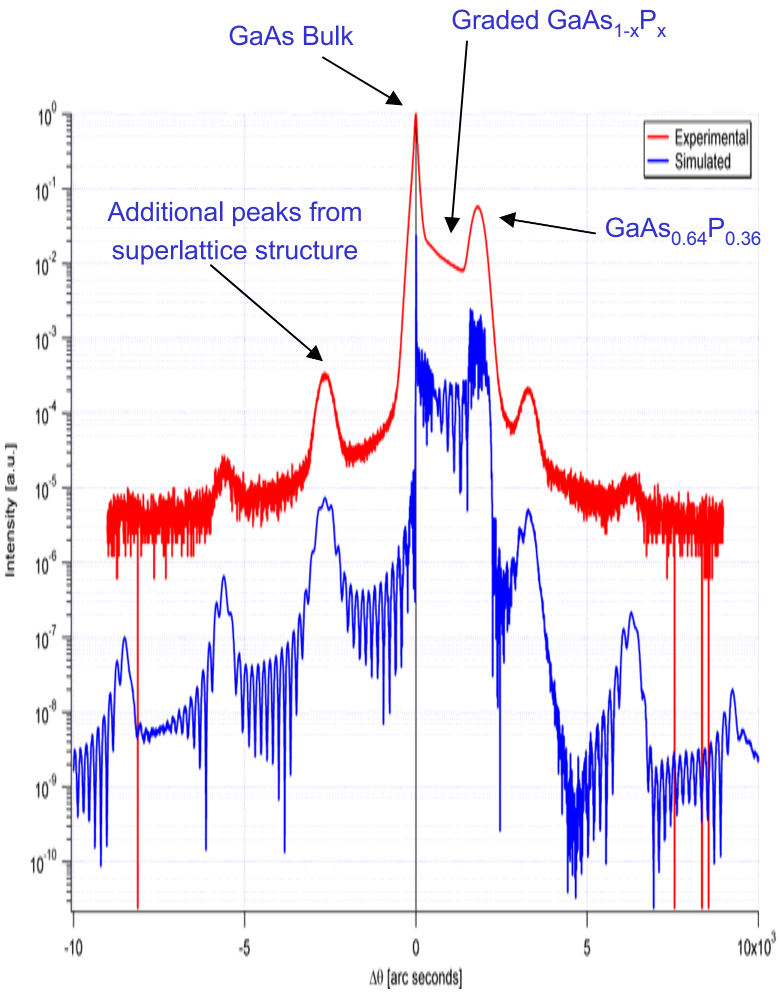


Polarized Electron Source Group

Rocking Curve (004) scan from SVT-3682

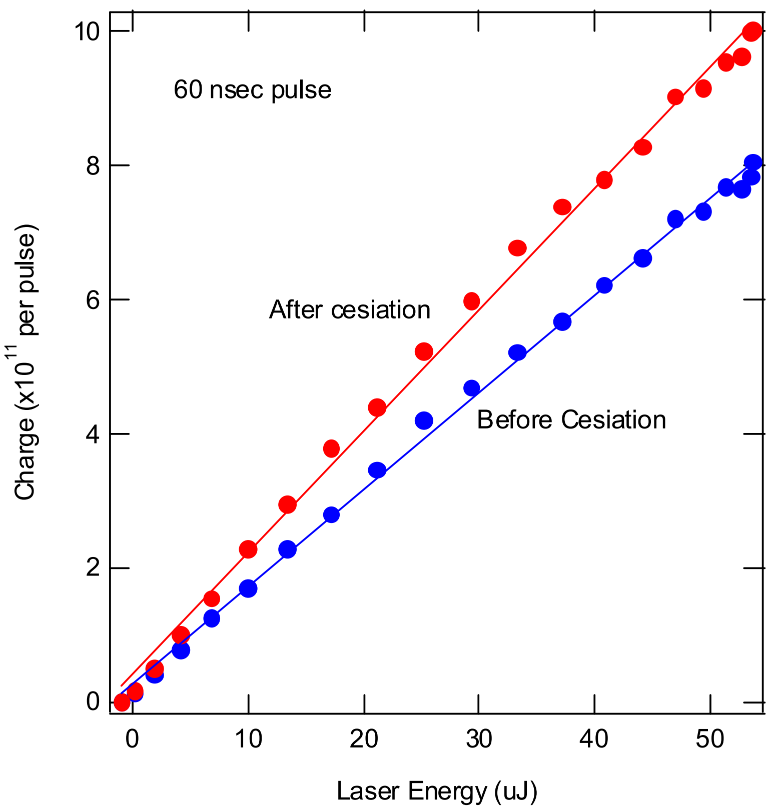
- Both SVT-3682 and SVT-3984 are superlattice cathodes:
  - MBE grown Be-doped (SVT Associates).
  - Barrier width: 30Å
  - Well width: 30Å
  - Phosphorus fraction in GaAsP: 0.36
  - Layer number: 16
  - Highly-doped surface layer thickness: 50Å

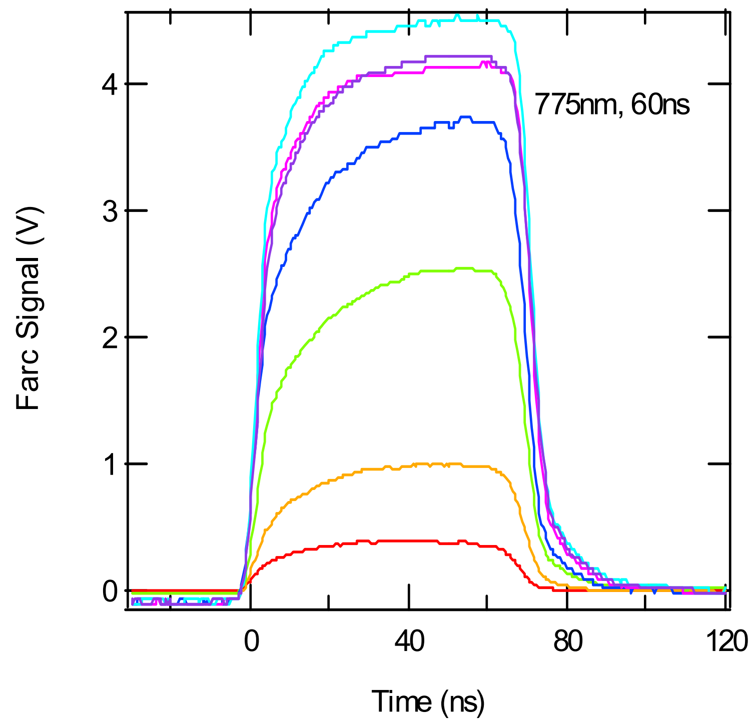
- XRD analysis on SVT-3682
  - Well Width = Barrier Width = 32Å
  - Phosphorus fraction in GaAsP: 0.36



No Charge Limit

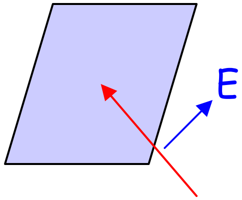
$1{\times}10^{12}$ e- in 60 ns



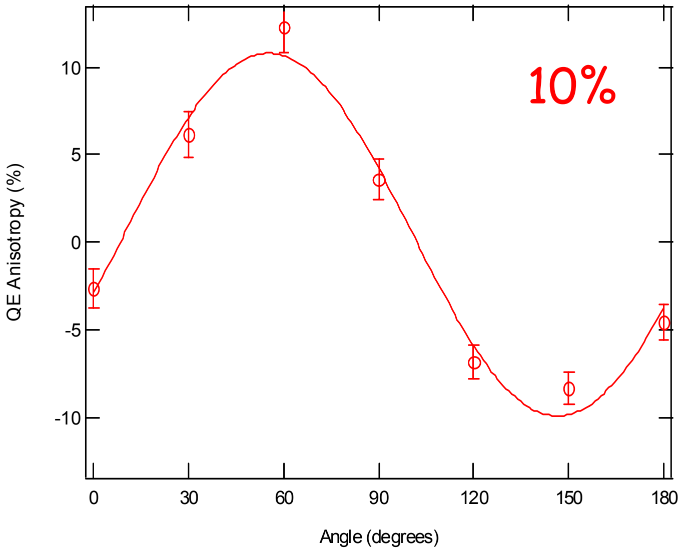


QE Anisotropy

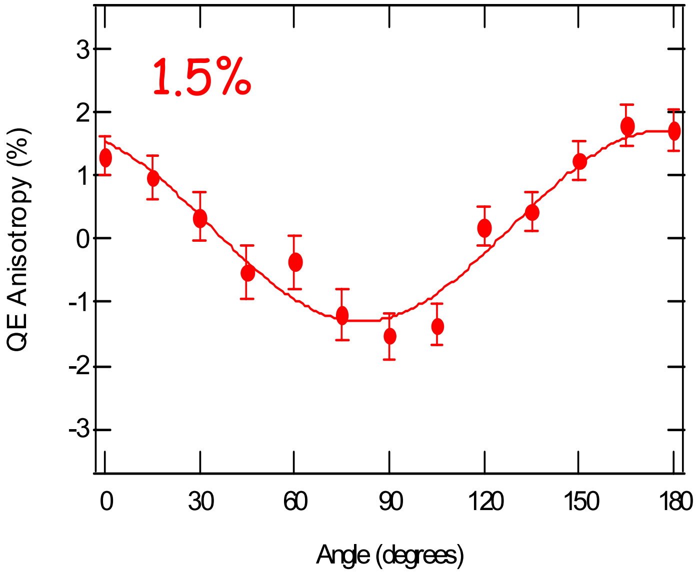
Strain relaxation



Strained GaAs

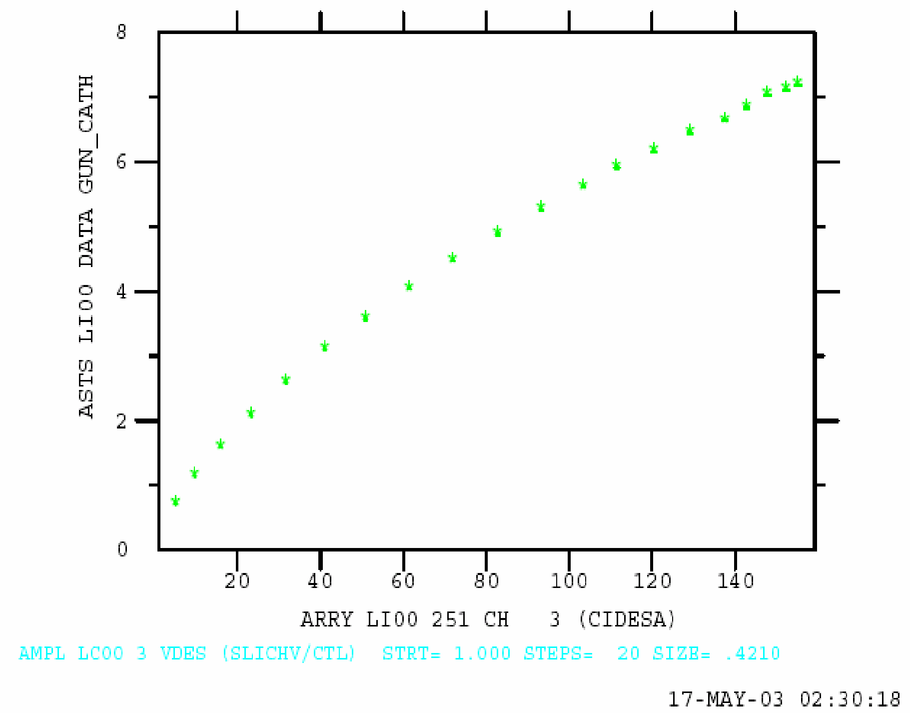


Strained superlattice

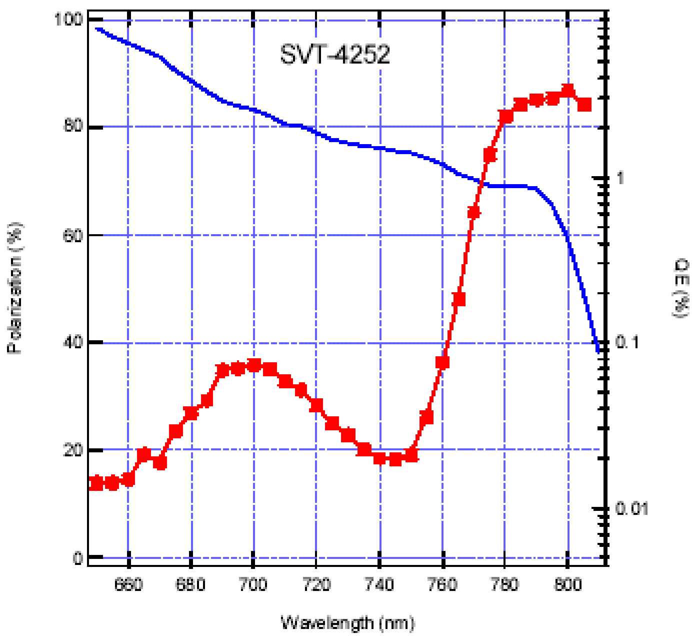


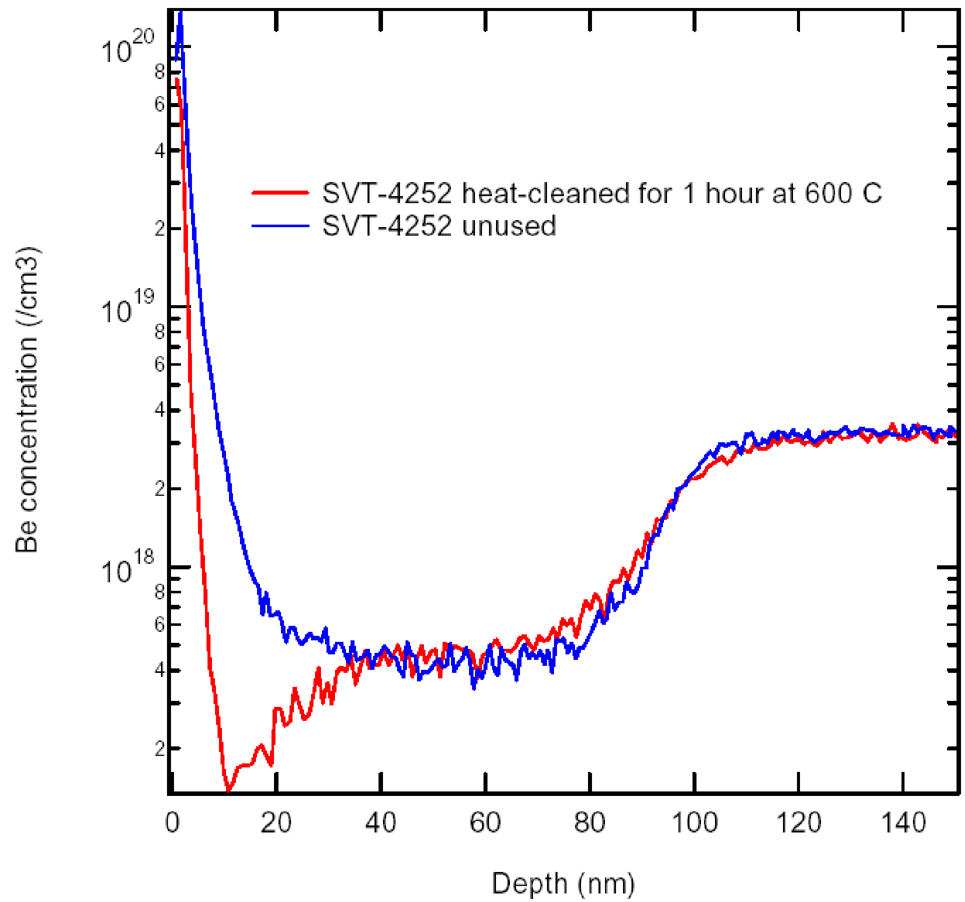
E158 again

- Cathode installed in May.
- But it shows a charge limi
  ~7×10^{11} e-/300 ns
- Cannot make NLC train charge but OK for E158.
- What happened?
- The 600° C heat-cleaning is destroying the high gradient doping profile.



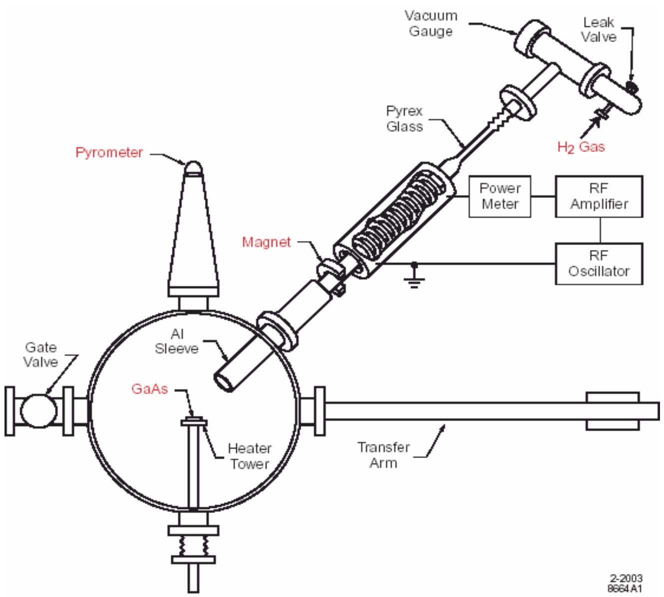
SVT-4252 Shows Charge Limit at Gun Test Lab
SVT-4246, SVT-4249 are ok

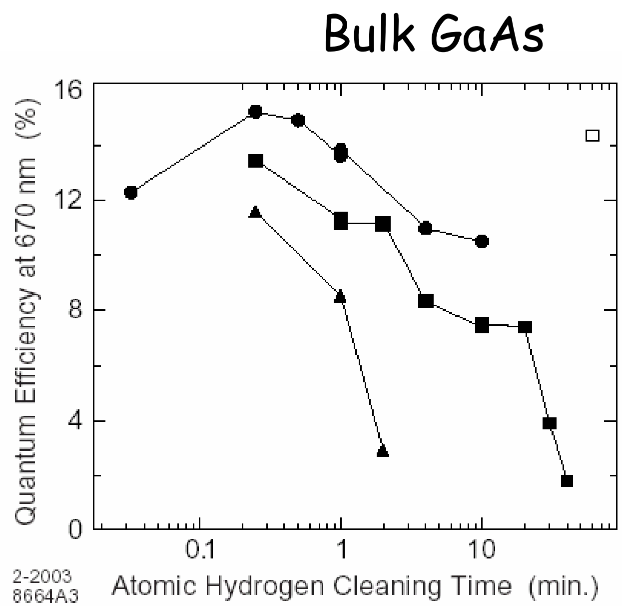




Polarized Electron Source Group

Atomic-Hydrogen Cleaning





Ga_2O_3 comes off at ~600° C.
Ga_2O comes off at ~450° C.

$Ga_2O_3 + 4H \rightarrow Ga_2O + 2H_2O\uparrow$

600° C heat-cleaning: QE ~ 11%
AHC + 450 ° C heat-cleaning: QE ~15%